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STATISTICAL PROCESS CONTROL IN THE HYBRID MICROELECTRONICS MANUFACTURING INDUSTRY; A NAVY VIEW POINT

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ABSTRACT

The U.S. Navy is concerned with receiving high quality hybrid microelectronic circuits. The Navy recognizes that in order to obtain high quality circuits a manufacturer must have an effective statistical process control (SPC) program implemented. The implementation of effective SPC programs is an objective of the military hybrid microelectronics industry. Often the smaller sized manufacturers in the industry have little SPC implementation, while the larger manufacturers have practices originally developed for the control of other product lines outside the hybrid technology area. The industry recognizes that SPC programs will result in high quality hybrid microcircuits which the U.S. Navy requires. In the past, the goal of the industry had not been to put in effective process control methods, but to merely meet the government military standards on the quality of the hybrids they produce. This practice, at best, resulted in a "hit or miss" situation when it comes to hybrid microcircuit assemblies meeting military standards. The U.S. Navy through its MicroCIM program has been challenging and working with the industry in the area of SPC practice methods. The major limitations so far have been a lack of available sensors for the real time collection of effective SPC data on the factory floor. This paper will discuss the Navy's efforts in bringing about effective SPC programs in the military hybrid manufacturing industry.

INTRODUCTION

The Navy has helped to implement SPC programs within the hybrid microcircuit assembly (HMA) industry by various means. Projects have been funded directly from system commands such as the Space and Naval Warfare Command (SPAWAR) and from Navy Laboratories. One program which has directly impacted the HMA industry is the MicroCIM program (Microelectronics for Computer Integrated Manufacturing). The MicroCIM program was sponsored by the Navy's Manufacturing Technology office. During the program, an Ad-Hoc Advisory Panel composed of industry and government experts convened several times. The Panel's primary function was to advise the Navy of the industries needs in the area of Computer Integrated Manufacturing and manufacturing automation. One of the needs which the panel expressed was for improved automated process equipment for near real time collection of statistical process control data. Another need was low cost SPC software that can reside on PCs or minicomputers. These needs were prevalent throughout most of the HMA industry because of the nature of the industry.

The military HMA industry is typical of many electronics manufacturing industries in that it is composed of mostly small volume manufacturers and just a handful of large volume manufacturers. The large volume manufacturers often are further along in the implementation of SPC. These manufacturers usually have sales over 100 million dollars, representing thousands of produced hybrids. Almost none of these large manufacturers produce military hybrids as their sole product. Some are multi-product corporations where the produced hybrids are not their major product. The HMAs are used most often for internal products. The large HMA manufacturing operations borrow technology from their other product lines for use in the HMA production area. These "borrowed" SPC technologies and methods are tailored for use in the HMA area. Consequently, large companies are able to quickly incorporate SPC automation, while small companies must depend on external sources (system integrators and the like) . This is one reason why the large manufacturers are ahead in the SPC area for HMAs. For some large manufacturers, investment in SPC is not a large risk since the technology is developed internally. While being costly, the investment is not a significant portion of the corporations total capital investment due to its various product lines.

The majority of the military HMA industry are small sized manufacturers that collectively produce much less than 50 million dollars worth of hybrids per year. These companies face a host of problems. One problem is if a small company has an SPC program in place (and they

often do not), the company uses mostly manual data collection for SPC purposes. Manual data collection is time consuming and error prone. While this type of quality assurance program was adequate for meeting past military standards and company internal requirements, it is apparent that this is no longer the case. The antiquated methods which small companies are still actively using reduces their competitive position relative to the more automated HMA manufacturers who can identify out of control product and processes. Another problem is the good possibility that SPC programs may be a requirement in future military standards. Already, the new general military specification for hybrids, Mil-H-38534, has a strong encouragement for the use of SPC in place of the traditional quality inspections. In the 1990 Hybrid Circuits Industry Overview, Integrated Circuits Engineering Corp. foresaw the coming SPC requirements: "The value of a strong SPC program has been recognized as a means of significantly improving the overall control and resulting quality of the manufacturing process. SPC will become an essential tool for companies desiring to remain competitive." [1: p.2-6] This is especially true in the military HMA market.

Monitoring product quality in HMA manufacturing is essential in achieving process efficiency for better productivity and yield [2: p.38]. For the military, better HMA yield results in higher quaiity and more efficient weapons systems. Through Mil-H-38534, the Department of Defense has opened a door for manufacturers to benefit by investing in an SPC program. This door leads to certification of SPC processes which in turn nullifies the requirement for 100% inspection on those processes. 100% inspection is time consuming and costly, so it is worthwhile for manufacturers to invest in an SPC program. Unfortunately, for small companies, this investment is beyond their capabilities. They often do not have the capital to develop automated SPC data collection equipment. They do not have the personnel to implement a factory wide SPC/DOE program nor can they afford to contract out the work.

In addition, many current and all future HMAs will have extremely tight specifications which will only be achievable from a high quality SPC program. Examples of these tighter specifications can be seen in the current thrust toward multi-chip modules (MCMs) which are highly complex HMAs. Manufacturers whether small, medium, are large must have an effective SPC program to meet these specifications. For these reasons it is necessary for the large number of smaller volume military HMA manufacturers to implement state of the art SPC programs. In order to be assured of a stable and high quality supply of HMAs for current and future weapon systems, it is beneficial for the Navy to assist this industry.

In the following sections, I will first discuss the importance of Mil-H-38534 to the acquisition of Navy HMAs. I will then detail three projects that the Navy has partially funded with military HMA manufacturers using ManTech funds. These projects were managed by the MicroCIM program office. The first project, at Raytheon Corp., has SPC data collection and analysis as one of its goals. The second project, at CTS Inc., has shop floor data collection and SPC analysis as its primary goal. The third project sought to establish a list of parameters which can be used for SPC.

MIL-H-38534B

This document was referred to earlier as being the General Specification for Hybrid Microcircuits. It establishes requirements for hybrid microcircuits and specifies the quality which must be met in the acquisition of these devices. The projects discussed earlier have as one of their goals to conform to this specification and especially its requirements concerning SPC. Manufacturers who produce hybrid microcircuits conforming to this specification can be certified by the responsible government qualifying activity. Mil-H-38534 compliant manufacturers have several competitive advantages over others in the industry when competing for Navy hybrid microcircuit procurement dollars. One advantage is that the manufacturer can use sampling inspection for those processes which call for 100% inspection of product. This is an

advantage to both the qualifying manufacturer and the customer. The manufacturer gains from an improved and robust process with few problems. The customer (U.S. Navy) gains from the receipt of high quality hybrid microcircuits at an eventually reduced cost due to less rework and operational failures.

Mil-H-38534 states, "as a minimum, the SPC program should include training, definition of controlled critical processes, installation of statistical control techniques, and a control action system as defined by JESD19-88."[3: 4.1.2.2 p.29] The specification recommends certain processes as being well suited for SPC, but also states that SPC should not be limited to these processes alone. To have a qualified SPC program a manufacturer must provide the following information; sample frequency, sample size, reject criteria, allowable rework, and disposition of failed product or lot for a given process. One of the reasons Raytheon starts with 100% inspection in their project is to proof out their process for the qualification requirements.

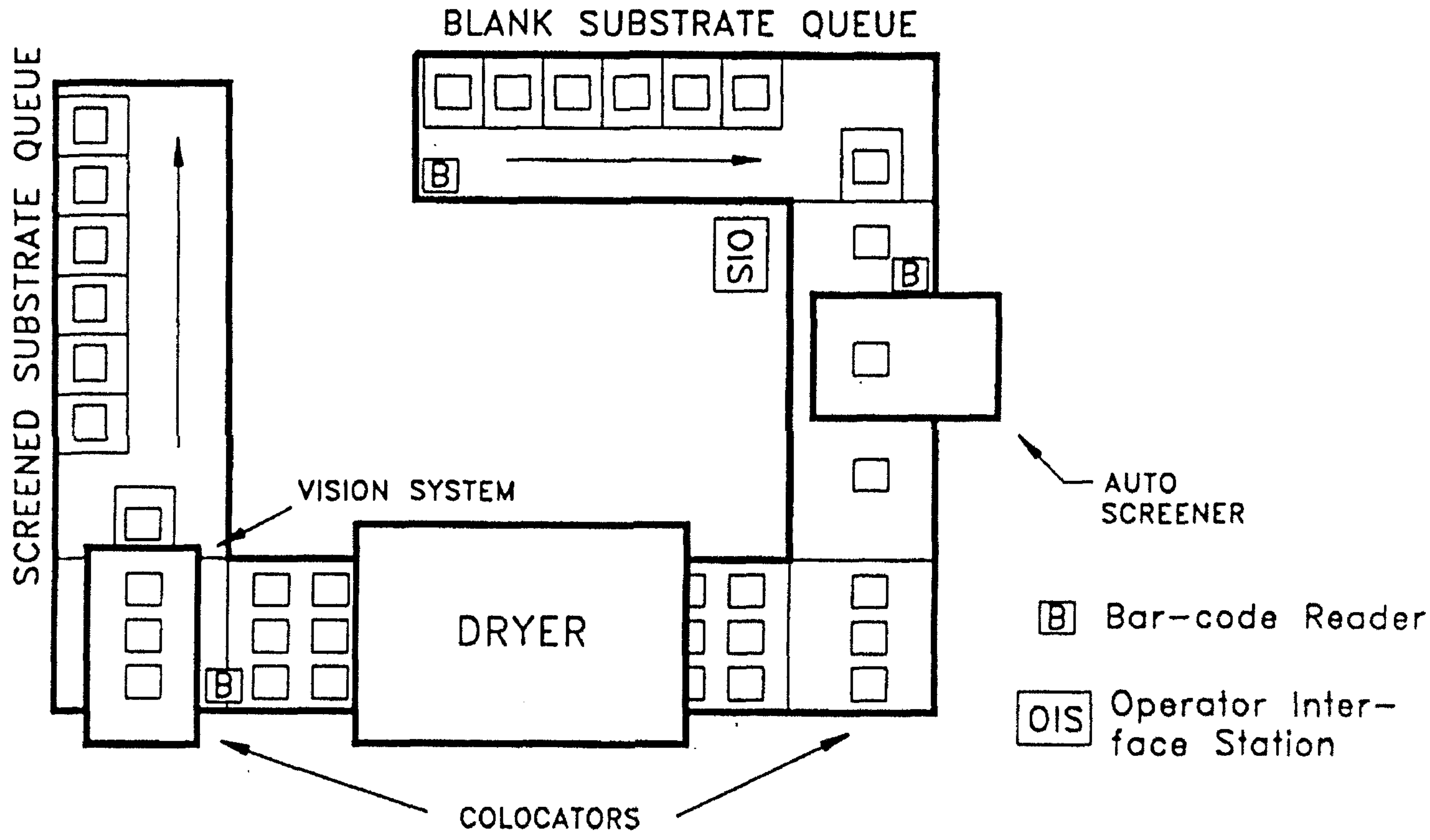
If a manufacturer has an established SPC program in place, they are still responsible for compliance to all terms of their government contract. Sampling inspection, as part of manufacturing, is acceptable for ascertaining conformance to requirements. It is up to the manufacturer to assure that the SPC program and inspections implemented will be adequate for meeting the quality standards of Mil-H-38534 and the general requirements of Mil-Std-883 (Test Methods and Procedures for Microelectronics). Mil-H-38534 also outlines the minimum number of samples, inspections, and tests required to conform to the product assurance levels of Mil-Std-883. These outlines are written for hybrid device elements, screening operations, process qualification, and data collection.

RAYTHEON

In 1990, the Navy implemented a Manufacturing Technology (ManTech) project at Raytheon Corp.'s Quincy, Massachusetts hybrid microcircuit assembly plant which had SPC improvement as part of its goal. The goal of the project was to automate the HMA substrate production process which is manually intensive in many companies within the industry. Specifically, the SPC portion of the project attempted to implement a low cost method of in-process verification of HMA substrates during the substrate fabrication phase. The verification would be used in conjunction with a real-time feedback SPC system to identify when the Screening Process was behaving abnormally. The project was called the Automated Substrate Production Cell.

Raytheon is large company and is a high volume producer of HMAs. The Navy teamed with Raytheon for several reasons, the first being that their HMA manufacturing plant is at the cutting edge of HMA technology including SPC technology. Also, the division has the skilled personnel necessary to perform the investigation and develop the ManTech project. And, the corporation had the capital to share in the project development cost. Both Raytheon and the small sized companies in the industry would benefit from the low cost developments.

The in-process verification consisted of a machine vision system controlled by a hybrid substrate (a ceramic circuit base) component recognition software, see figure 1. Dry substrates pass underneath the vision system and the system compares the image of the substrate to a golden template version generated on a CAD system. The vision system searches for various characteristics of the substrate. Any defects found are classified by the software and then fed back to an operator control station where a trained operator implements any corrective action as necessary. The defect is then sent into a database. The implementation of this system improves product consistency at the very least. The system is first used as an inspection/verification station where every HMA is inspected. As the system proves itself by building a database of statistical data, the verification will be done on a sampling basis.



ASPC Automatic Screener with Machine Vision

Figure 1

The inspection is performed at a point in the substrate production process where substrates which fail inspection can be reprocessed at the least cost. It is cost effective for the inspection to be completed early so that errors can be found as early as possible. The results of the inspection are used in an SPC program. Since particular defects are classified and placed in a database, these defects can be used to detect trends, out of control conditions, and other SPC factors. With appropriate software and hardware controllers, this SPC analysis can be done in near real time. Thus, adjustments to the process are implemented readily. As stated earlier, 100% inspection of product is required in order to prove the process and build up a database of defect data. As the process maintains a stable condition, inspection on a sampling basis is implemented. Sampling serves to verify that the process is in control and to find areas for continuous process improvement.

Fortunately, appropriate SPC software and machine vision hardware exist "off the shelf" for this SPC program. The major limitation is suitable defect classification and recognition software. This is the major developmental portion of the project. Table I shows some of the defects this system would have to recognize and classify. In figure 2 are representations of some of the defect classes listed in Table I. The cost for an HMA manufacturer to develop a similar system, based upon the System Design, System Requirements, and System Architecture documents from this project , will be under 100,000 dollars. It is expected that the majority of the HMA manufacturing industry can withstand this low cost.

TABLE I
Machine Vision Defect Classes

Conductor Void
Open Conductor
Foreign Material
Blisters
Smeared Paste
Crack > 5mills
Resistor Overlap

CTS CORP.

The NAVY contracted with CTS Corp. on a Manufacturing Data Collection and Analysis (MDCA) project. CTS Corp. was chosen because they are a major producer of HMAs. HMAs are their major product line, and they had obtained the personnel as well as upper management support to implement the project. Two-thirds of the project were composed of elements which the Navy sees as vital to having SPC methods and practices implemented throughout the military HMA industry. These two-thirds were Shop Floor Data Collection and Statistical Process Control. The goals of these parts of the project were to reduce scrap, reduce rework, reduce cycle times, improve reliability, and improve data analysis capability.

Data Collection

The impetus for CTS's interest in the shop floor data collection (SFDC) project was to improve current inefficiencies so as to produce better HMAs and improve competitive position. CTS faced several problems which are pervasive throughout the military HMA industry. First was that a manual pen and paper SPC system was cumbersome to maintain and inefficient. A heavy amount of paper work was required to conform to traceability and conformance requirements. Second, manual data collection from the shop floor was too slow for a quick response to out of control conditions. Third, alarms to indicate abnormal situations at specific shop floor systems were not being generated and sent to the respective systems. Fourth, data collected often was duplicated to provide sufficient reporting and for redundancy issues. Fifth, manual

Class B

3.2.1.2 Metallization voids.

a. Void(s) in the metallization, excluding bonding pads, that leaves less than 50 percent of the original metallization width undisturbed (see figure 2032-40b).

k. Contact overlap between the metallization and the resistor in which the actual width dimension "x" is less than 50 percent of the original resistor width (see figure 2032-49b).

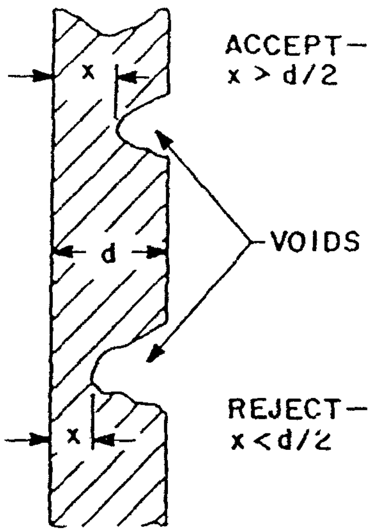


Figure 2a: Conductor Voids

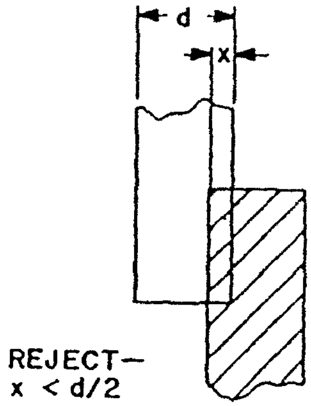


Figure 2c: Resistor Overlap

c. Any crack that exceeds 5.0 mils in length (see figure 2032-44b).

d. Any crack that does not exhibit 1.0 mil of separation from any active circuit area or operating metallization (see figure 2032-44b).

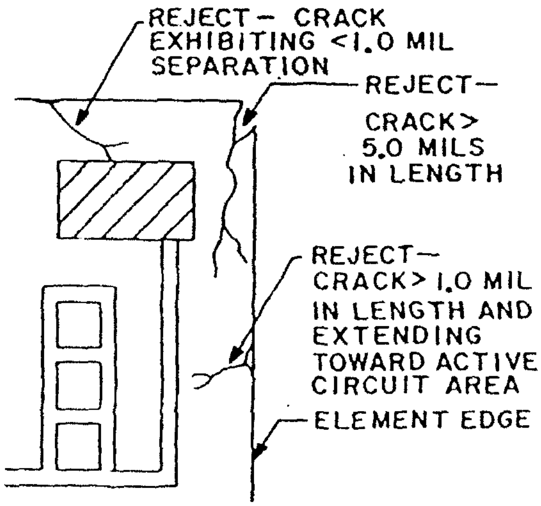


Figure 2b: Cracks greater than 5 mils in length

data collection was also prone to human recording and keying errors. Sixth, processes from which data is not being collected were prone to high scrap and rework. This results in higher labor overhead costs. Lastly, the type of data to be collected had to be identified/classified by human judgment.

In addition, the lack of a central database available for data collection was a problem. The uses of a database are to store collected data, long term archiving of data to facilitate future data retrieval, and analysis of long term data. A database also helps to meet the intent of Mil-H-38534 which states that the data collected for SPC and testing purposes are auditable. CTS chose a method for storing the data using a relational database. It will facilitate the integration of data into their factory control system. Another intent of Mil-H-38534 is to eventually replace source inspections with SPC data. The use of a database will help towards this goal.

The solution to the above problems has several requirements. First is the automated or semi-automated collection of data at shop floor processes and sending the data to a global database. The database will have to allow for formatted storage of information from various dependent and interdependent sources. The database system must collect and route data in near real time. A user interface to the database must allow queries of specific pieces of data, the generation of data reports, viewing of alarms as well as trends, and charts. The database will have to reside on low cost hardware with software that allows for quick access to the database information. Controllers on shop floor processes will acquire, format, and send the data to the database.

Any solution must recognize that, depending upon the process equipment being used, some processes will be more amenable to data collection than others. For example, the Wire Pull, Destructive Die Shear, Laser Trim, and Lead Shear processes are well suited for electronic collection of data. The remaining processes will have some combination of electronic and manual collection, ie. data collected electronically but entered into database manually. Even so, this type of implementation will be more efficient than that done currently.

SPC software will run "on top of" the database system. The software will analyze incoming data rapidly and generate alarms when out of control conditions occur. The alarms will be sent to the appropriate destinations.

SPC

The second part of the MDCA project concentrated on SPC. Specifically it concentrated on what data to collect from manufacturing and how to route alarms to their appropriate locations. Table 2 presents a sample list of parameters which can be collected manually from HMA process stations. These parameters are analyzed by manufacturers to identify process problems. However, as stated earlier, this collection process is not nearly as effective as an automated near real time system.

TABLE 2

Process	Parameter
Circuit Screening	Material Property
Circuit Screening	Material Viscosity
Circuit Inspection	Wire Pull Strength
Circuit Inspection	Solderability
Dielectric Inspection	Crossover Capacitance
Resistor Screening	Ink Viscosity
Resistor Screening	Film Thickness
Resist Screening	Ink Resistivity

CTS's past SPC operations were similar to those of some of the military HMA industry. Process control was implemented only after several flaws were detected. SPC charts were located at the various process stations and the operator plotted and measured the data. Processes were changed only when a piece of data was outside control limits. Trend analysis was not performed since it is time consuming. As stated previously, small manufacturers do not have the personnel to commit to data analysis.

The Navy required that the solution to the SPC portion of the problem be developed for computers generally available to industry. Off the shelf hardware and software was planned for use in the project. The software used for analyzing incoming data must be configurable so that future developments will be compatible with it. The software must also allow off-line analysis of the data for design of experiment purposes. The operating system needs to be a standard system such as UNIX or DOS.

The data collected will have four descriptors associated to it; data source, data destination (apart from the SPC system), form of data (electronic or paper source), and description of data. Data collected from process stations will be portioned into two categories; statistical process control data and operation attribute data. The SPC data will be analyzed and stored within the database system.

PROCESS PARAMETERS DATA LIST

The MicroCIM program contracted with Treese and Associates Inc. to develop a list of measurable parameters used during the processing of HMAs. The purpose of this list is to have available to the industry the typical range of values for HMA process variables used during manufacturing. The list is a first step towards developing methods for the measuring and controlling these parameters during processing. This will bring about cost effective and higher quality product.

Thick film, thin film, and multi-chip modules process parameters compose the list. For each of these HMA types, the document starts with substrate fabrication process parameters and progresses on to final assembly, inspection, and test. Figure 3 shows the first page from the multi-chip module portion of the list. For each parameter, nine categories of data are included. The first category is an operation number which identifies a parameters location within the list. The second category is the name of the process where the parameter is located. The third category describes the parameter/property to be measured. The units of measurements for the parameter are listed in the fourth category. A typical range of values found in the industry for the parameter is listed in category five. The SPC format used for tracking the parameter is listed in category six. Category seven lists how data on the parameter is collected, either manual or automatic. Category eight lists whether the process in which the parameter is located is manual or automatic. The last category shows the military document which governs the parameter, if any.

Unfortunately, there are many blank spaces through out the list. Some blank spaces exist because the particular category did not apply to the corresponding parameter. Other blank spaces exist because data could not be found to fill those spaces. It is expected that the industry will fill those blank spaces as time goes on. Some parameters may be deleted from the list as they are found not to be significant to HMA processing.

CONCLUSION

The U.S. Navy is an advocate for the use of Statistical Process Control methods within the military hybrid microcircuit assembly industry. The Navy MicroCIM program has directed over two million dollars in ManTech funds towards this goal. The Navy has worked with the

GENERIC, MULTI-CHIP ASSEMBLY PROCESS FLOW

OPERATION #	PROCESS DESCRIPTION	PROPERTY	UNITS OF MEASURE	TYPICAL VALUE\RANGE	SPC FORMAT	DATA	PROCESS TYPE	CONTROLLING DOCUMENT
4400	PLASMA CLEAN	Operating frequency	MHz	13				
4400		Operating presure	Microns (Hg)	5				
4400		Power, RF	Watts	100				
4400		Cleaning time	Minutes	10				
4400		Gases for plasma	$String$	Oxygen, Argon, etc.				
4400		Partial pressure of atmosphere	Percent	10% Oxygen, 90% Argon				
4400		Number of units to be cleaned (load)	Unitless	?				
4410	SCREEN CONDUCTIVE EPOXY	Screen mesh	Wire/inch	?				MIL-STD-883, METHOD 2017.7
4410		Screen tension	?	?				MIL-STD-883, METHOD 2019.4
4410		Screen breakaway distance	Mils	?				MIL-STD-883, METHOD 5011
4410		Squeegee applied pressure	Lbs/sq.in \ linear in.	1-10 psi/in. of squeegee				
4410		Squeegee deposition velocity	Inches/second	2-6				
4410		Squeegee hardness	Durometers	?				
4410		Substrate to screen distance	Mils	?				
4410		Number of squeegee passes	Unitless	1, 2, or 3				
4410		Material properites	?	?				
4410		Material properties						
4410		Minimum layer thickness	Mils	?				
4410		Maximum layer thickness	Mils	?				
4410		Emulsion thickness on screen	Mils	2-3				
4410		Screen weave angle to substrate	Angular degrees	22, 45, or 90				
4410		Substrate registration to screen	X-mils, Y-mils	?				
4420	CURE EPOXY	?	?	?				

Figure 3

industry as a partner and a customer in this area. It is expected that with continued efforts like the MicroCIM program, the HMA industry will be able to meet the Navy's future demand for high quality, complex HMAs. The military HMA industry realizes that future design and process requirements necessitate the incorporation of automated SPC methods.

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